Microfiber-based Sensor for Measuring Uric Acid Concentrations

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***Abstract*— Microfiber sensor is proposed and demonstrated using a fiber optic displacement sensor (FODS) based on intensity modulation technique for measurement of different concentrations of uric acid. The proposed sensor uses single-mode fiber (SMF) tapered using flame brushing technique to enhance the evanescent field around the fiber core to interact with the uric acid. The tapered area is bent manually and sets vertically on a clamp, facing the mirror in the beaker. It is placed within the linear range of a sensor's displacement curve of 0 to 5000 µm. The calibration of tapered fiber sensor was done both in the air and diluted water. The sensor is capable of measuring the concentrations of uric acid from 100 ppm to 500 ppm with a measured sensitivity of 0.0218 dBm/ppm. The linearity and resolution of the proposed sensor are 99.21% and 28.219 ppm, respectively. In addition, the proposed microfiber FODS sensor using SMF exhibit good stability and repeatability. It provides numerous advantages in terms of simple design, less production cost and operation without forfeiting its sensitivity.**

***Index Terms*— Displacement sensor; Microfiber; Single-mode fiber; Uric acid concentration.**

I. INTRODUCTION

Biosensor is one of the fast-growing research area and the used of sensor devices such as optical, piezoelectric and electrochemical for the analysis has gained tremendous attention due to the importance of the biological element which affects everyday life. Uric acid is an organic compound consists of carbon, nitrogen, oxygen, and hydrogen, which can be produced by a human being and it is a normal component of urine. The impact of having a high concentration of uric acid in the human body can lead to several diseases such as gout, Lesh-Nyhan syndrome, hyperuricaemia, kidney stone and physical disorder [1] and also link to hypertension and renal disease [2]. The screening of concentration of uric acid in the human body is crucial for the early diagnosis of a patient suffering from these diseases. Hence, the need for uric acid biosensors is tremendously increasing [3-6]. A lot of sensor devices have been developed for detecting uric acid and one of the favorable choices is a fiber optic sensor (FOS), due to its immunity to be used in a high electromagnetic interference environment as well as low in cost and simple fabrication. To date, the most common technique used to sense uric acid has been reported in the literature whereby the sensing element is added to enhance the sensitivity of the sensor. Such works have been reported by Batumalay et. al. [7-9] which consists of ZnO, carbon-nanotubes and graphene as a sensing element. Tapered plastic optical fiber (POF) using a sol-gel method was used to coat the surface of the POF in order to improve the sensitivity of the proposed sensor.

Tapered silica optical fibers (SOF) provides sufficient evanescent wave to trap the ZnO, along with the implementation of FODS for an effective measurement technique. FODS is chosen due to its ability to measure physical parameters with low cost and simple implementation. There are three main techniques in FODS which are fiber Bragg grating (FBG), Fabry-Perot interferometer (FPI) and light intensity modulation. The FBG sensor modulates the light wave inside the optical fiber when it stretches, therefore leads to strain displacement. On the other hand, FPI manipulates the phase of light to be modulated and shifted hence resulting in displacement measurement. Mach-Zehnder interferometer (MZI) use the same principle as FPI [10]. However, both techniques are complicated to construct, although it provides very good sensitivity [11]. With the two techniques limited by their complexity, light intensity modulation technique is simpler in terms of the arrangement with low operating cost and provides good parameters result. The scheme works by means of modulating the transmitted light intensity through reflection, fiber bending or by changing the medium through which the light propagates.

This work aims to develop a new silica-based fiber optic displacement sensor (FODS) that provides higher accuracy as a quantitative technique for measuring uric acid concentrations. It employs intensity-modulated sensor based on an evanescent field from the tapered fiber. The FODS is used as a measurement technique to investigate the uric acid concentrations between 100 ppm to 500 ppm. The calibration of tapered fiber sensor was done in air and diluted water. In this work, the FODS technique is used concurrently with the tapered fiber to achieve better performance and accuracy of the fiber sensor. Current projects, mostly rely on the FODS or tapered fiber without combining both techniques. This project aims to achieve better performance by a combination of microfiber and FODS. Microfiber is used as an added element due to its ability to confine a fraction of optical powers in an evanescent field around the fiber core. It is then used to analyze the different concentrations of uric acid with higher accuracy compared to the current non-tapered FODS sensor utilizing POF.

II. METHODOLOGY

Microfiber structure will be produced using a flame brushing technique from a standard single-mode fiber (SMF) with core and cladding diameters of 8 µm and 125 µm, respectively. Figure 1 shows a schematic diagram of microfiber fabrication setup which uses an oxy-butane burner as a torch. The oxygen gas and butane gas are supplied from separate gas cylinders. In the fabrication, oxygen and butane gas pressures are regulated at the optimum pressure of ~5 psi each to keep the convective air flow from the flame at a low level. A short length of polymer buffer jacket was stripped out and cleaned by using isopropanol. Then, the fiber was cut using fiber cleaver before being fused using an arc fusion technique. It is then mounted on a pair of motorized translation stages. During tapering, the torch moves and heats at a temperature of around 1400 ^{0}C along the uncoated segment of fiber while the fiber is being stretched. The moving torch provides uniform heat to the fiber and the microfiber is produced with good uniformity along the heated region. The transmission spectrum of the microfiber has been monitored during the fabrication by using an amplified spontaneous emission (ASE) source from an Erbium-doped fiber amplifier (EDFA). It is injected into one end of the SMF while the other end is connected to the optical spectrum analyzer (OSA).

The experimental setup for measuring various uric acid concentrations using a microfiber is shown in Figure 2. Each end of the microfiber was connected to the ASE (Amplified Spontaneous Emission) and OSA (Optical Spectrum Anayzer) as an input light and output detection, respectively. The sensing area which is the tapered fiber is being bent manually and placed vertically on a clamp. The bent tip area is facing the mirror in the empty beaker. After the tapered fiber was steadily placed, the ASE is turned on and the spectrum was observed by OSA. In the calibration stage, the vertically placed tapered fiber is moved away from the mirror in 50 µm steps and at each position, the output is recorded and observed. The linear range of the displacement sensor is identified for 5000 µm in which the attached micrometer moves towards the mirror, starting from 13 mm (default) to 18 mm. The experiment started with distilled water and continued with different concentrations of uric acid. In order to ensure the bended fiber is still attached, both diluted water and uric acid is being placed into or removed from the beaker using a syringe. On the other hand, the experiment is done in a closed area with constant humidity condition since the microfiber is easily broken if it is exposed to an extreme air.

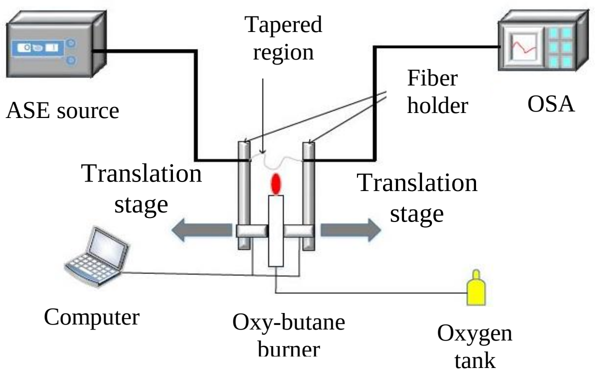

Figure 1: Microfiber fabrication set up

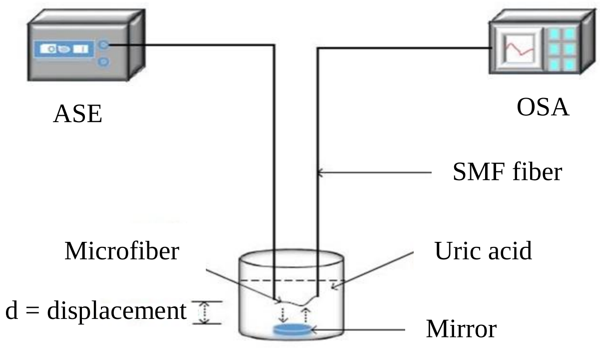

Figure 2: The experimental setup for measuring uric acid concentrations using microfiber FODS

III. Results and Discussion

From the observation in calibration stage, the use of a micrometer translation stage provides displacement (0 – 5000 µm) and known concentrations (100 – 500 ppm) of uric acid due to the changes in displacement. Figure 3 shows the output spectra of the microfiber in the air. It is noted that the change in output power due to the change in displacement can be clearly seen in which the displacement of about 13 mm exhibits highest output power. Apart from that, an interferometer output can be seen as a result of the tapered fiber, making it easier to check the changes in terms of intensity. The performance of the tapered SMF was then tested to measure the uric acid concentration. In contrast with the calibration, it is observed that the output power has increased in increments of displacement. Based on figure 4, a linear front part of the curve is sharply incline due to the overlapping between the transmitted and received light cone angle. The linear back part of the curve shows a slight increased in output power with the increasing displacement as a result of reductions in power density. It can be seen from figure 4 that the output power is decreased when the uric acid concentrations are increased. In the tapered fiber region, the evanescent field at surrounding region will increase and the surrounding tapered region becomes a passive cladding, hence the decreased in the intensity of light is due to increase of scattered light to the surrounding medium. In fact, figure 5 shows the variation of refractive index of uric acid in different concentrations. It is observed that the refractive index is increased as the uric acid concentration increased.

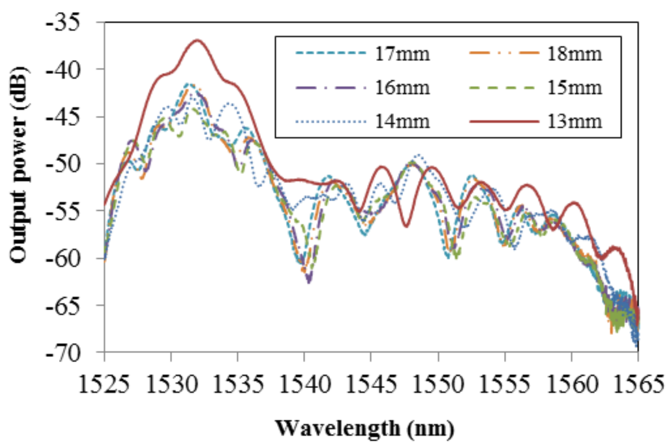

Figure 3: Output spectra of microfiber in air

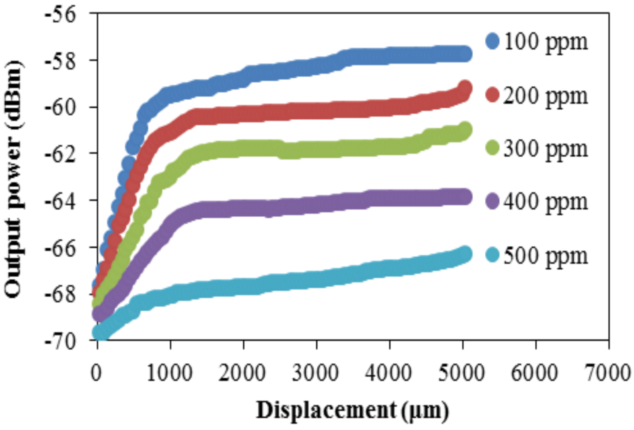

Figure 4: Output power of the sensor (dBm) as a function of displacement (µm) for various uric acid concentrations

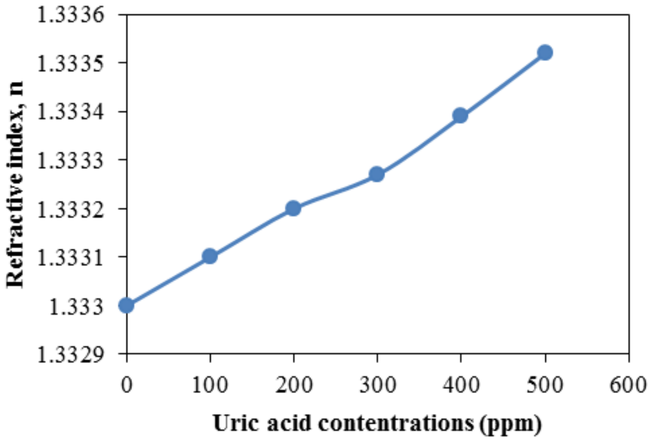

Figure 5: Refractive index of uric acid concentrations

From the results, the refractive index of uric acid solutions varies from 1.3331 to 1.33352 as the uric acid concentrations increased from 100 to 500 ppm. When uric acid replaced distilled water, the refractive index of the surrounding region of the tapered fiber also increased. The increased in uric acid concentrations alter the refractive index difference between core and the passive cladding, therefore more light would escape to the surrounding medium resulted in decreased in intensity.

Figure 6 shows the output power against uric acid concentrations at the fixed displacement of 18 mm from the reflective mirror. It is found that the intensity of the transmitted light decreases linearly with the increase in uric acid concentrations from 100 to 500 ppm. The sensitivity of the sensor is obtained at 0.0218 dBm/ppm, with slope linearity of more than 99.21% and limit of detection or resolution of 28.219 ppm. In short, the combination of tapered fiber and FODS sensor demonstrates a comparable sensitivity to the change of uric acid concentration as compared to the result reported by [7-9]. The tapered fiber accommodates the changes in refractive index of the surrounded area and modulates the light propagating through the fiber. It is observed that the intensity of the interferometer is found to be decreasing, as the uric acid increases.

The characteristics of the proposed sensor are summarized in table 1. Overall, the sensor can be deduced as stable with a standard deviation of 0.615 dBm for a silica microfiber with FODS. In measuring uric acid within a range of 100 to 500 ppm, the sensor displays a sensitivity of 0.0218 dBm/ppm with slope linearity of more than 99.21%. Its limit of detection/resolution is 28.219 ppm. The resolution was calculated by dividing the standard deviation with the sensitivity, and thus the system is more efficient when the resolution is lower.

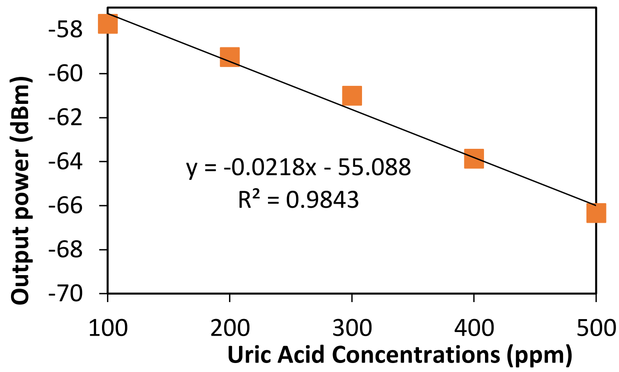

Figure 6: The output power against uric acid concentrations.

Table 1
Performance of microfiber displacement sensor in measuring uric acid concentration.

Parameters	Value
Resolution (ppm)	28.219
Standard Deviation (dBm)	0.615
Linearity (%)	99.21
Sensitivity (dBm/ppm)	0.0218
Linear Range (ppm)	100– 500

IV. Conclusion

We have demonstrated the microfiber-based intensity modulated fiber optic displacement sensor for monitoring of 100 ppm to 500 ppm uric acid concentrations. The intensity of the ASE output power was measured and the results show the inverse linear relationship with the uric acid concentrations. The sensitivity of the sensor is obtained at 0.0218 dBm/ppm with the linearity of more than 99.21%. The 18 mm displacement from the reflective mirrors exhibits the highest intensity of the output power. It is attributed to the modification of the core cladding refractive index difference with the assistance from the evanescent field produced by the tapered fiber. The proposed sensor uses for about 5 cm of the tapered areas as a sensor head, thus allows a compact, simple and low-cost sensor device measurement.

Acknowledgment

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